AGS Tune Control Notes

C.J. Gardner

May 13, 2005

1 Basic Formulae

The horizontal and vertical tunes at a given field B are respectively

$$Q_H = Q_H^0 + \frac{B_0}{B}\{A_{11}I_H + A_{12}I_V\} \tag{1}$$

$$Q_V = Q_V^0 + \frac{B_0}{B}\{A_{21}I_H + A_{22}I_V\} \tag{2}$$

where I_H and I_V are the currents in the horizontal and vertical tune quad strings. The parameter B_0 is a fixed field chosen to be 0.82 kilogauss. The parameters Q_H^0, Q_V^0, A_{11}, A_{12}, A_{21}, A_{22} depend on the field. For a well behaved machine the dependence is weak, but for the case of the AGS with warm and cold snakes the dependence is quite strong.

2 Measure A_{11} and A_{21}

To measure A_{11} and A_{21} at a given field, we fix I_V and vary I_H. This gives

$$Q_H + \Delta Q_H = Q_H^0 + \frac{B_0}{B}\{A_{11}(I_H + \Delta I_H) + A_{12}I_V\} \tag{3}$$

$$\Delta Q_H = \frac{B_0}{B}A_{11}\Delta I_H, \quad A_{11} = \frac{B}{B_0}\left(\frac{\Delta Q_H}{\Delta I_H}\right) \tag{4}$$

and

$$Q_V + \Delta Q_V = Q_V^0 + \frac{B_0}{B}\{A_{21}(I_H + \Delta I_H) + A_{22}I_V\} \tag{5}$$

$$\Delta Q_V = \frac{B_0}{B}A_{21}\Delta I_H, \quad A_{21} = \frac{B}{B_0}\left(\frac{\Delta Q_V}{\Delta I_H}\right). \tag{6}$$

3 Measure A_{12} and A_{22}

To measure A_{12} and A_{22}, we fix I_H and vary I_V. This gives

$$Q_H + \Delta Q_H = Q_H^0 + \frac{B_0}{B} \{A_{11} I_H + A_{12}(I_V + \Delta I_V)\} \tag{7}$$

$$\Delta Q_H = \frac{B_0}{B} A_{12} \Delta I_V, \quad A_{12} = \frac{B}{B_0} \left(\frac{\Delta Q_H}{\Delta I_V} \right) \tag{8}$$

and

$$Q_V + \Delta Q_V = Q_V^0 + \frac{B_0}{B} \{A_{21} I_H + A_{22}(I_V + \Delta I_V)\} \tag{9}$$

$$\Delta Q_V = \frac{B_0}{B} A_{22} \Delta I_V, \quad A_{22} = \frac{B}{B_0} \left(\frac{\Delta Q_V}{\Delta I_V} \right). \tag{10}$$

4 Bare Tunes

Parameters Q_H^0 and Q_V^0 are called bare tunes because they are the values of Q_H and Q_V given by (*1) and (*2) when I_H and I_V are zero. This is simply a definition; in practice the machine may not be stable with I_H and I_V equal to zero. Having measured Q_H, Q_V, A_{11}, A_{12}, A_{21}, and A_{22} at a given field, the bare tunes given by

$$Q_H^0 = Q_H - \frac{B_0}{B} \{A_{11} I_H + A_{12} I_V\} \tag{11}$$

$$Q_V^0 = Q_V - \frac{B_0}{B} \{A_{21} I_H + A_{22} I_V\}. \tag{12}$$

5 Starting Tunes

Ahrens has suggested that the predicted tunes for a given field and for given currents in the tune quad strings may be useful parameters. Calling these horizontal and vertical "starting tunes" and denoting them with a superscript S, we have

$$Q_H^S = Q_H^0 + \frac{B_0}{B} \left\{ A_{11} I_H^S + A_{12} I_V^S \right\} \tag{13}$$

$$Q_V^S = Q_V^0 + \frac{B_0}{B} \left\{ A_{21} I_H^S + A_{22} I_V^S \right\} \tag{14}$$

where I_H^S and I_V^S are the predicted "starting currents" in the horizontal and vertical tune quad strings. In terms of the starting tunes, the bare tunes are

$$Q_H^0 = Q_H^S - \frac{B_0}{B}\left\{A_{11}I_H^S + A_{12}I_V^S\right\} \tag{15}$$

$$Q_V^0 = Q_V^S - \frac{B_0}{B}\left\{A_{21}I_H^S + A_{22}I_V^S\right\}. \tag{16}$$

Inserting these into equations (*1) and (*2) we obtain

$$Q_H = Q_H^S + \frac{B_0}{B}\left\{A_{11}(I_H - I_H^S) + A_{12}(I_V - I_V^S)\right\} \tag{17}$$

$$Q_V = Q_V^S + \frac{B_0}{B}\left\{A_{21}(I_H - I_H^S) + A_{22}(I_V - I_V^S)\right\}. \tag{18}$$

These equations have the conceptual advantage that only physically realizable tunes appear in them. Moreover, the difference between starting tune and measured tune is expected to be small. Carrying out the measurement procedure described above one obtains A_{11}, A_{12}, A_{21}, A_2 at a given field. These measured parameters, along with the measured tunes Q_H and Q_V, then give measured starting tunes

$$Q_H^S = Q_H - \frac{B_0}{B}\left\{A_{11}(I_H - I_H^S) + A_{12}(I_V - I_V^S)\right\} \tag{19}$$

$$Q_V^S = Q_V - \frac{B_0}{B}\left\{A_{21}(I_H - I_H^S) + A_{22}(I_V - I_V^S)\right\}. \tag{20}$$

Whether one uses starting tunes or bare tunes as parameters is a matter of taste. The measured parameters A_{ij} and the procedure for obtaining them are the same in either case. Since the existing Optics Control program uses the bare tune parameterization this is what we shall continue to use.

6 Additional Parameters

In an AGS with warm and cold snakes, modeling has shown that the dependence of parameters Q_H^0, Q_V^0, and A_{ij} on field B is very strong at injection and during early acceleration. Ahrens has found that this dependence goes as various powers of (B_0/B). This suggests that we introduce additional parameters such that

$$Q_H = Q_H^0 + A_H\frac{B_0}{B} + B_H\left(\frac{B_0}{B}\right)^2 + C_H\left(\frac{B_0}{B}\right)^3 + D_H\left(\frac{B_0}{B}\right)^4$$

$$
\begin{aligned}
&+ \frac{B_0}{B}\{A_{11}I_H + A_{12}I_V\} + \left(\frac{B_0}{B}\right)^2\{B_{11}I_H + B_{12}I_V\} \\
&+ \left(\frac{B_0}{B}\right)^3\{C_{11}I_H + C_{12}I_V\} + \left(\frac{B_0}{B}\right)^4\{D_{11}I_H + D_{12}I_V\} \qquad (21)
\end{aligned}
$$

and

$$
\begin{aligned}
Q_V &= Q_V^0 + A_V\frac{B_0}{B} + B_V\left(\frac{B_0}{B}\right)^2 + C_V\left(\frac{B_0}{B}\right)^3 + D_V\left(\frac{B_0}{B}\right)^4 \\
&+ \frac{B_0}{B}\{A_{21}I_H + A_{22}I_V\} + \left(\frac{B_0}{B}\right)^2\{B_{21}I_H + B_{22}I_V\} \\
&+ \left(\frac{B_0}{B}\right)^3\{C_{21}I_H + C_{22}I_V\} + \left(\frac{B_0}{B}\right)^4\{D_{21}I_H + D_{22}I_V\}\,. \qquad (22)
\end{aligned}
$$

Here the parameters A_{ij}, Q_H^0, Q_V^0 are allowed to be programmed as functions of B as before, but the parameters A_H, B_H, C_H, D_H, A_V, B_V, C_V, D_V, B_{ij}, C_{ij}, D_{ij} are simply constants independent of B that can be chosen at will. Setting these constant parameters all equal to zero gives equations (*1) and (*2). Note that by defining

$$
q_H^0 = Q_H^0 + A_H\frac{B_0}{B} + B_H\left(\frac{B_0}{B}\right)^2 + C_H\left(\frac{B_0}{B}\right)^3 + D_H\left(\frac{B_0}{B}\right)^4 \qquad (23)
$$

$$
q_V^0 = Q_V^0 + A_V\frac{B_0}{B} + B_V\left(\frac{B_0}{B}\right)^2 + C_V\left(\frac{B_0}{B}\right)^3 + D_V\left(\frac{B_0}{B}\right)^4 \qquad (24)
$$

and

$$
a_{ij} = A_{ij} + \left(\frac{B_0}{B}\right)B_{ij} + \left(\frac{B_0}{B}\right)^2 C_{ij} + \left(\frac{B_0}{B}\right)^3 D_{ij} \qquad (25)
$$

we can write (*21) and (*22) as

$$
Q_H = q_H^0 + \frac{B_0}{B}\{a_{11}I_H + a_{12}I_V\} \qquad (26)
$$

$$
Q_V = q_V^0 + \frac{B_0}{B}\{a_{21}I_H + a_{22}I_V\}\,. \qquad (27)
$$

7 Using the Additional Parameters

One way to proceed would be to use equations (*23–*27) with the constants A_H, B_H, C_H, D_H, A_V, B_V, C_V, D_V, B_{ij}, C_{ij}, D_{ij} set equal to the values predicted by the MAD model. Carrying out the measurement procedure described above then gives a_{11}, a_{12}, a_{21}, a_{22}, q_H^0, q_V^0 as functions of B. Parameters Q_H^0, Q_V^0, A_{ij} are then

$$Q_H^0 = q_H^0 - A_H \frac{B_0}{B} - B_H \left(\frac{B_0}{B}\right)^2 - C_H \left(\frac{B_0}{B}\right)^3 - D_H \left(\frac{B_0}{B}\right)^4 \qquad (28)$$

$$Q_V^0 = q_V^0 - A_V \frac{B_0}{B} - B_V \left(\frac{B_0}{B}\right)^2 - C_V \left(\frac{B_0}{B}\right)^3 - D_V \left(\frac{B_0}{B}\right)^4 \qquad (29)$$

and

$$A_{ij} = a_{ij} - \left(\frac{B_0}{B}\right) B_{ij} - \left(\frac{B_0}{B}\right)^2 C_{ij} - \left(\frac{B_0}{B}\right)^3 D_{ij}. \qquad (30)$$

If the model is close to being correct, these parameters will depend only weakly on the field B.

If the values of the constants A_H, B_H, C_H, D_H, A_V, B_V, C_V, D_V, B_{ij}, C_{ij}, D_{ij} are way off, then one can again determine the coefficients a_{ij} and tunes q_H^0, q_V^0 for several values of the field B. Fitting equations (*23–*25) to this data (with Q_H^0, Q_V^0, A_{ij} now treated as constants independent of B) then gives values for all of the parameters.

8 Plan for Tune Control with Cold Snake

After much discussion it was decided that we will use equations (*1) and (*2) without the additional parameters discussed above. On day one of operation with the cold snake we will want to do the following:

1. Put model values for Q_H^0, Q_V^0, A_{ij} into Tune Control Program and set Q_H and Q_V to desired values at a discrete set of time points during the magnetic cycle.

2. Adjust Q_H and Q_V setpoints at the first of these points to get beam survival on the injection porch. Adjust Q_H and Q_V setpoints to get desired measured tunes on injection porch. Vary I_H and I_V to determine A_{ij}. Calculate Q_H^0 and Q_V^0 from these data.

3. Adjust Q_H and Q_V setpoints at each point in turn to get beam survival up to that point. Adjust Q_H and Q_V setpoints to get desired measured tunes at the point. Vary I_H and I_V to determine A_{ij}. Calculate Q_H^0 and Q_V^0 from these data.

4. Put the new values of Q_H^0, Q_V^0, and A_{ij} into the Tune Control Program and allow the program re-calculate new Q_H and Q_V setpoints keeping currents I_H and I_V fixed.